

The High-Current Energy Recovery Linac at Brookhaven National Laboratory

Presented at
LINAC12 Conference, Tel-Aviv, Israel



RHIC:
Discovery of a “perfect” liquid
of strongly interacting
quarks and gluons.
Deep mystery:
“missing” proton spin

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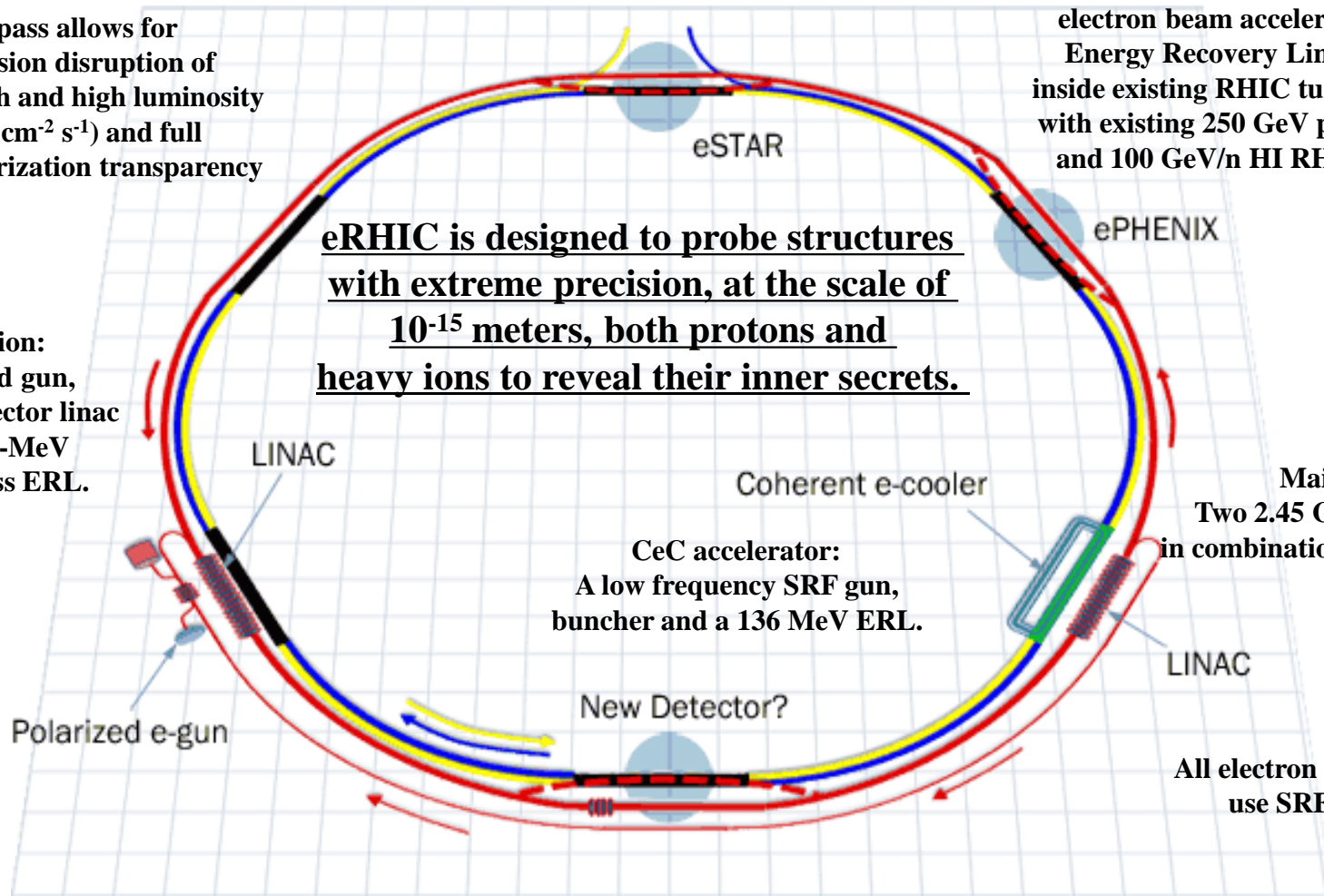
eRHIC: polarized electron ERL colliding with RHIC beams

Single pass allows for large collision disruption of electron bunch and high luminosity ($L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) and full electron polarization transparency

eRHIC: 5 – 30 GeV electron beam accelerated with Energy Recovery Linac (ERL) inside existing RHIC tunnel collides with existing 250 GeV pol. protons and 100 GeV/n HI RHIC beams

eRHIC is designed to probe structures with extreme precision, at the scale of 10^{-15} meters, both protons and heavy ions to reveal their inner secrets.

Injection: Polarized gun, 10 MeV injector linac and 600-MeV single-pass ERL.



Main ERL: Two 2.45 GeV SRF linacs in combination with six passes.


CeC accelerator: A low frequency SRF gun, buncher and a 136 MeV ERL.

All electron accelerators use SRF cavities

Not shown: Energy loss and energy spread compensation linacs, crab cavities for electrons and ions.

eRHIC R&D at the Collider-Accelerator Department

- eRHIC machine design
 - Lattice design
 - Wake fields and losses
 - Kink instability
 - IP design
 - Crab crossing
 - Small gap magnets
- Multi-pass high average current ERL
 - ERL highly-damped accelerating cavities
 - SRF photocathode gun
 - R&D ERL for 300 mA average current
- High current (50 mA) polarized electron gun
- Coherent electron cooling of hadron beam
- Misc. items: ERL BBU, photocathode R&D



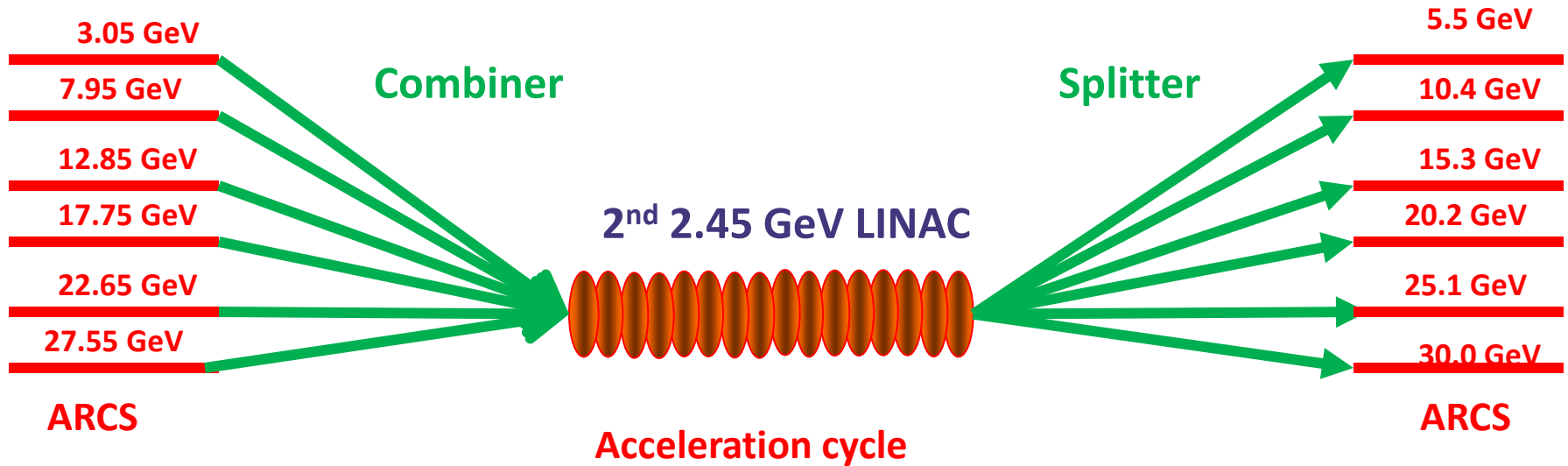
Innovative approach: Use an Energy Recovery Linac for the electron machine



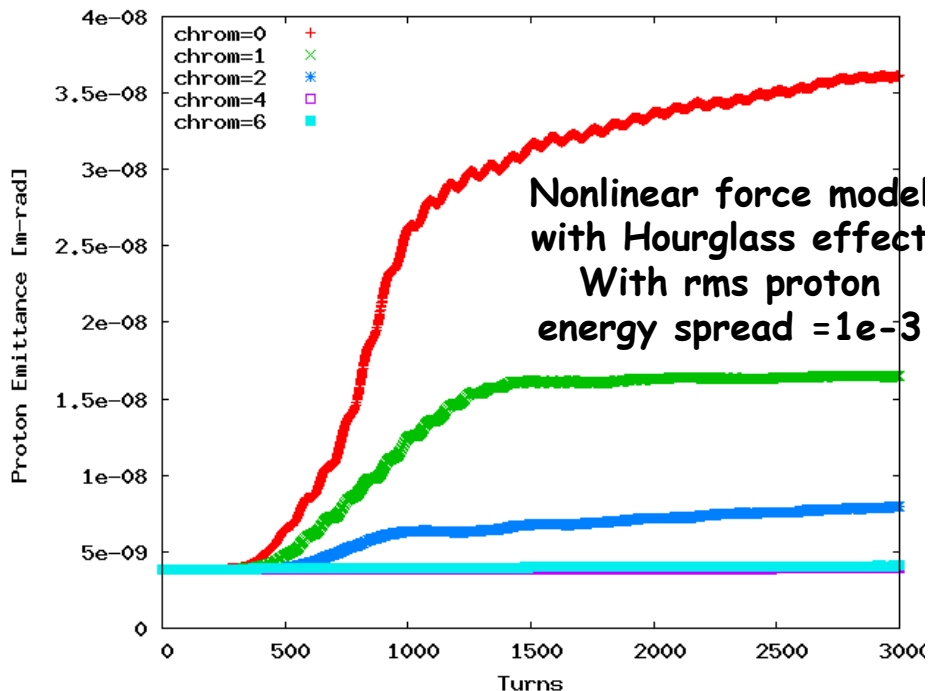
Innovative approaches: Funneling for the gun, and the concept of the FEL based CeC

Schematic diagram of the Combiner/Splitter 2nd LINAC at 2 o' clock (Acceleration cycle)

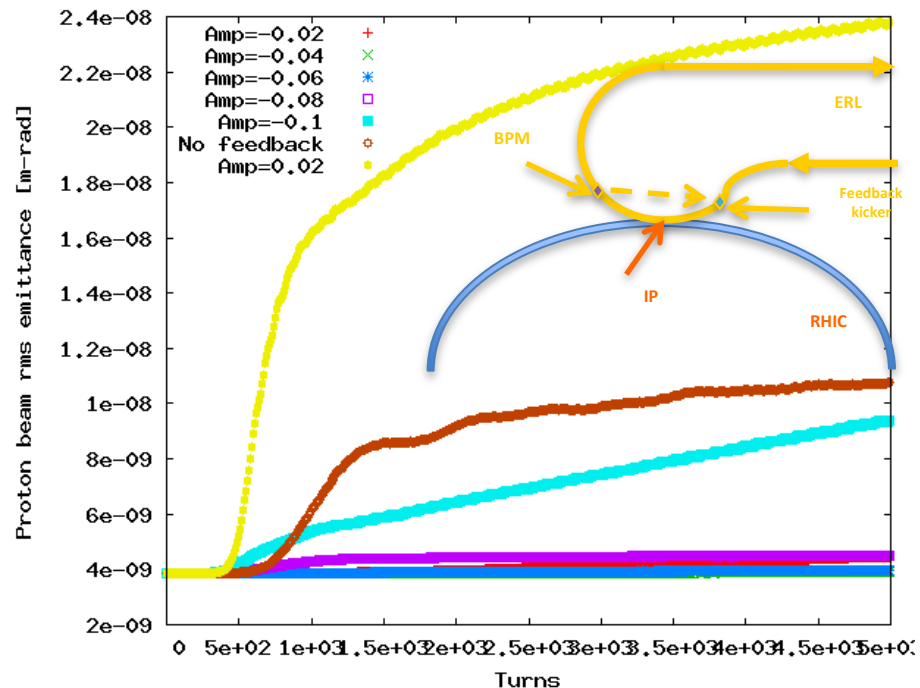
It is the system of the beam lines which **Combines** the beams of the **ARCS** into the **LINAC** or **Splits** the beams exiting the **LINAC** into the **ARCS**



Suppression of kink instability



By chromaticity: $\xi \sim +4$



Kink instability – a possible instability of the proton beam caused by its interaction with the electrons. Specific for linac-ring scheme.

704 MHz 5-cell niobium cavity for high-current ERL

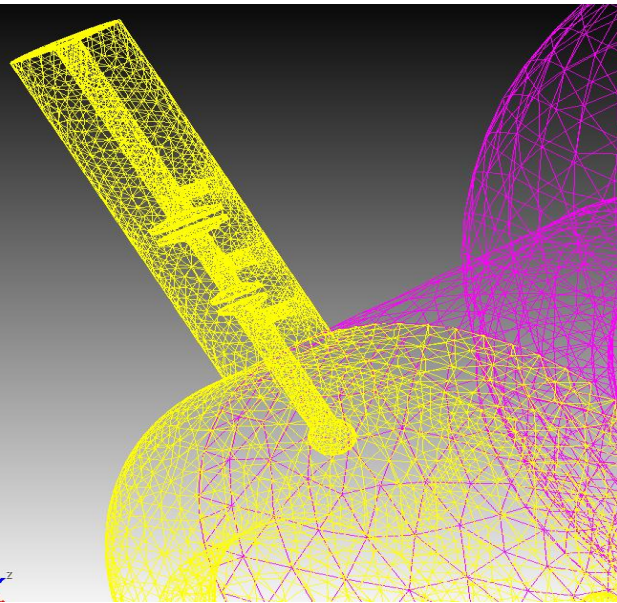
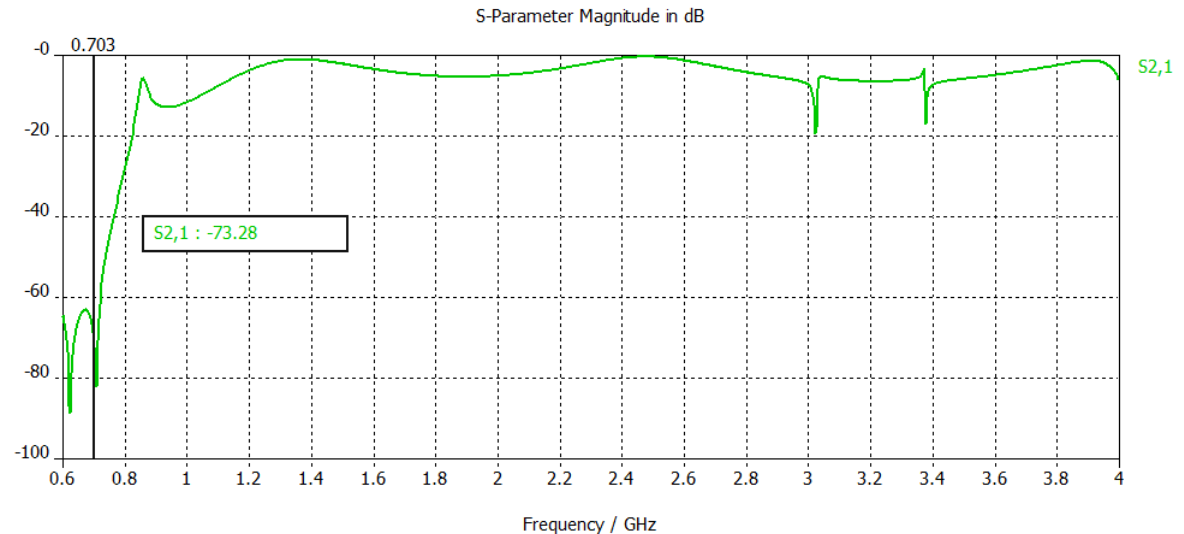
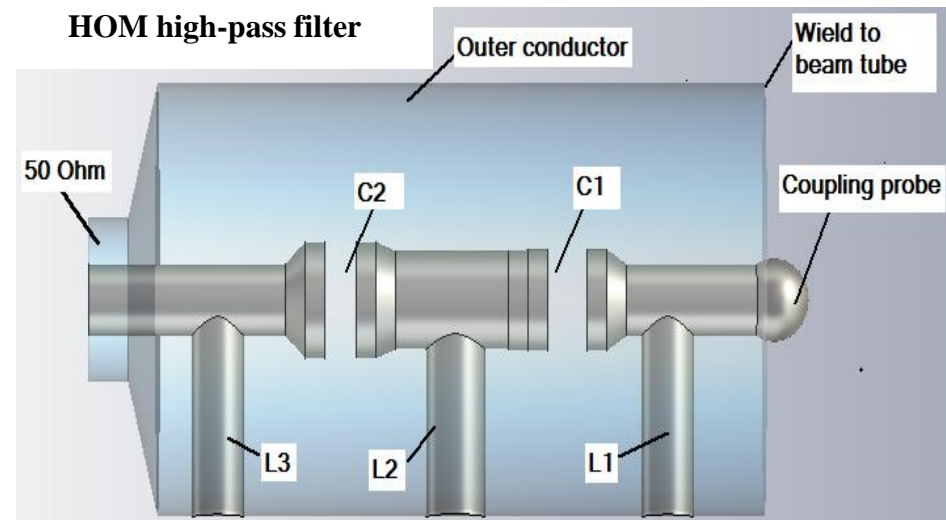


- Total HOM power to extract is 7.3 kW per cavity at eRHIC 3.5 nC, 50 mA, 6 passes up + 6 passes down energy (loss factor 3.5 V/pC).
 - See presentation MOPB063 by Sergey Belomestnykh in this conference on the eRHIC SRF linac

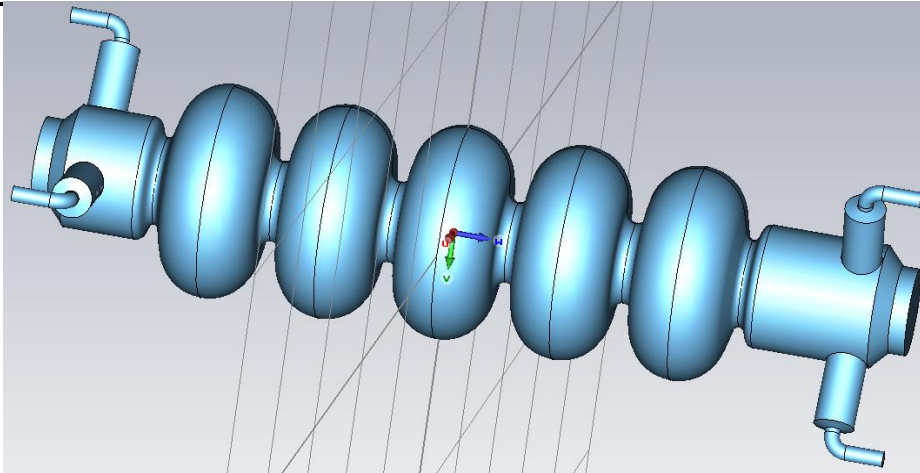
High-Current ERL R&D

HOM damping with antenna-type couplers

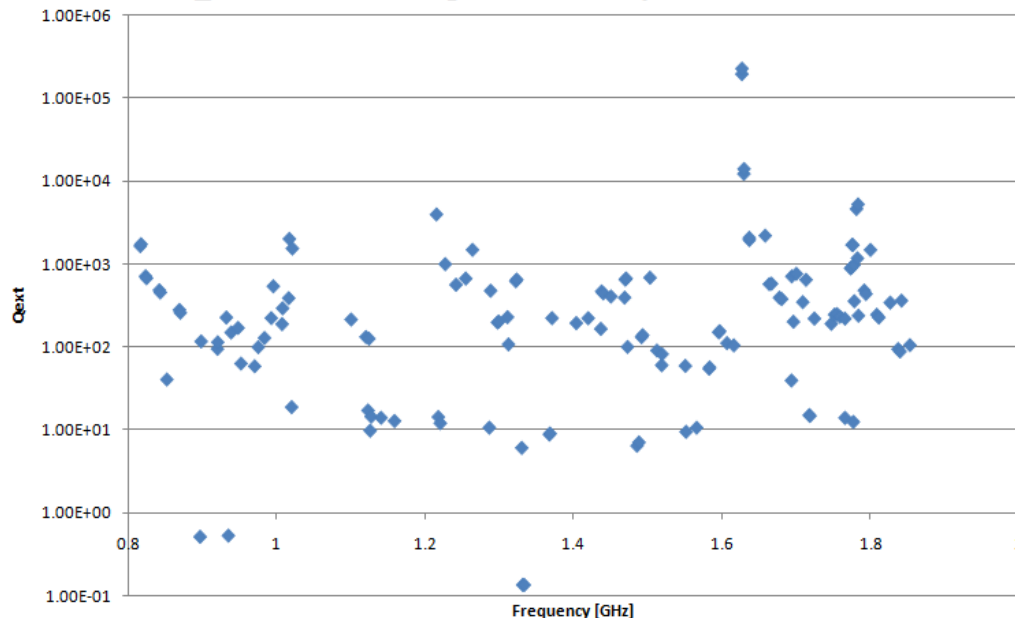
- A two-stage high-pass filter rejects fundamental frequency, but allows propagation of HOMs toward an RF load.
 - 1st HOM is at 0.82 GHz.



HOM damping

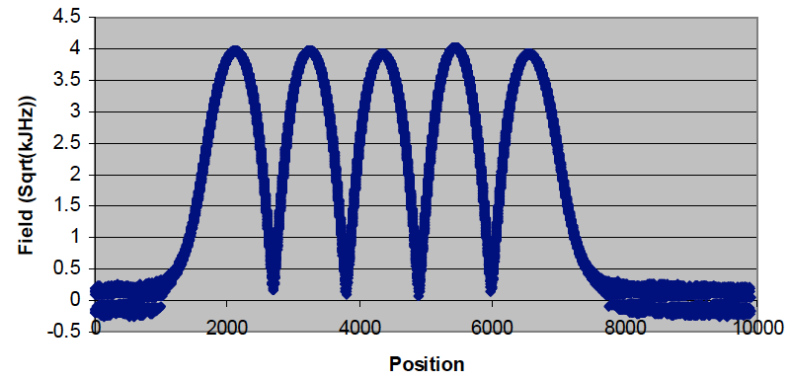


Q_ext with 2 120 degree HOM couplers at each side

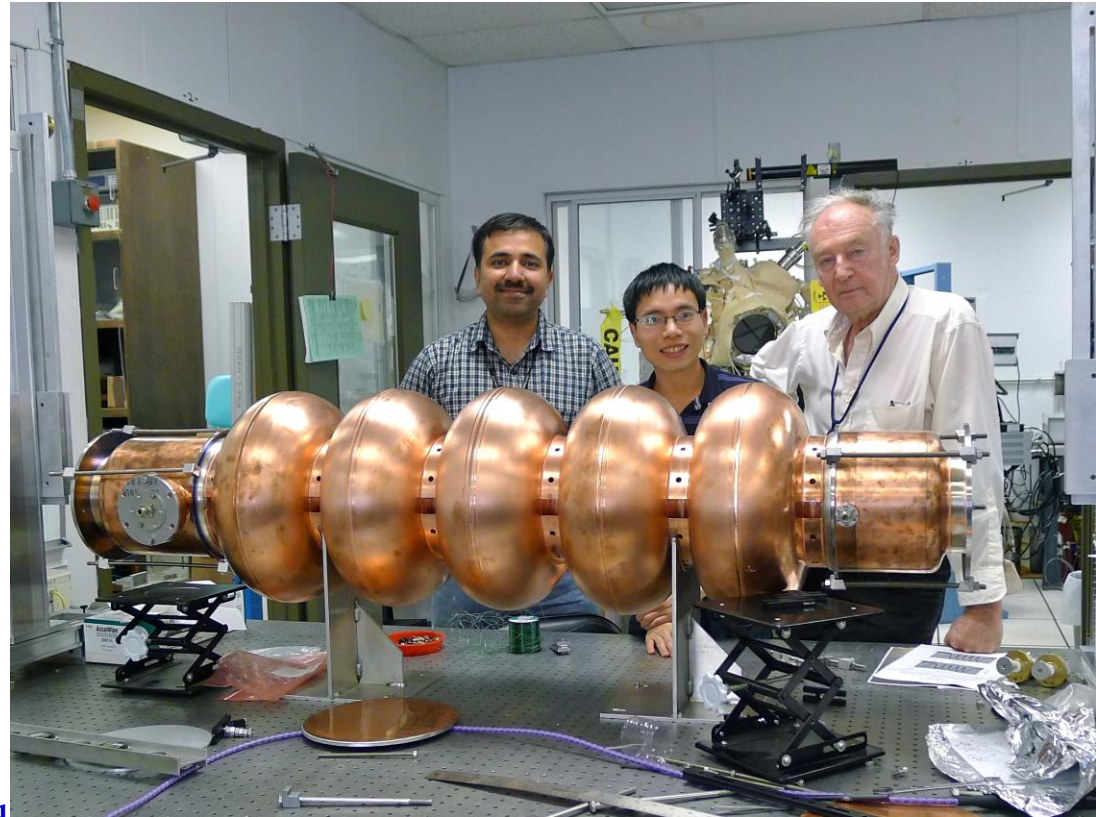


- Damping of dipole modes has been considered important to avoid beam breakup (BBU).
- We simulated a model with just two HOM couplers per side using CST MWS, showing excellent damping.
 - Modes at 1.62 GHz have R/Q of ~0.1 Ohm.
- Recent work by Vladimir Litvinenko points to a method of avoiding BBU by using the chromaticity in the ERL. See presentation xxxx in this conference.

The copper cavity prototype



Cavity was fabricated by AES.
Tuned to specs (98.5% field flatness).
Acceptance measurements are finished.
Detailed HOM studies done.



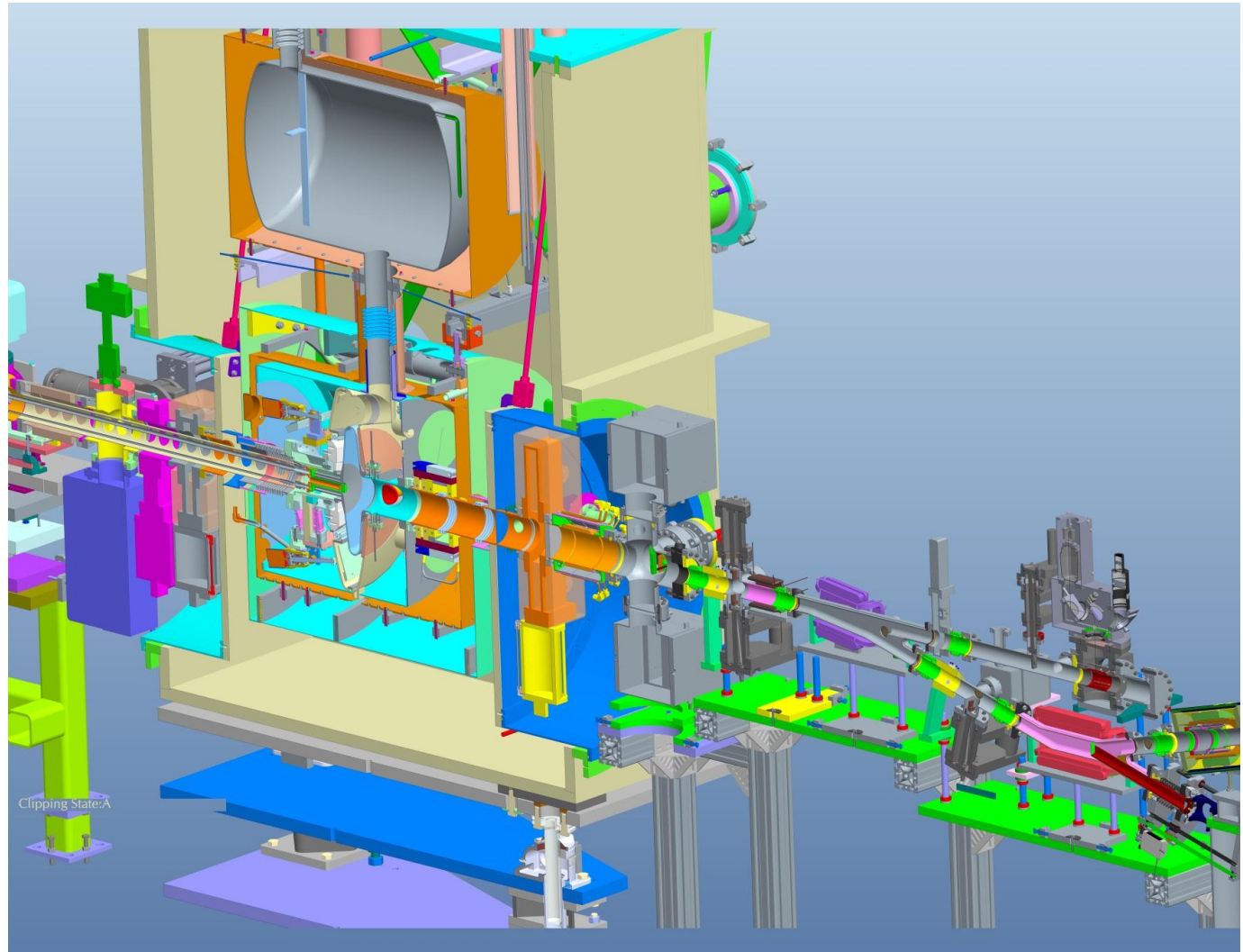
SRF Photocathode RF gun

Cut-away view
of the 704 MHz
elliptical half-cell
SRF gun.

Photocathode
injection is on the left, beam
transport is on the right.

More details in
Developing of
Superconducting
RF Guns At
BNL,

S. Belomestnykh
et al. MOPB064



SRF Photocathode RF gun

- The 704 half-cell elliptical shape SRF gun has two Fundamental input Power Couplers (FPCs) allowing to deliver 1 MW of RF power to 0.5 A - 2 MeV electron beam.
- HOM damping is provided by an external beam-line ferrite load with ceramic break.
- See presentation by Sergey Belomestnykh in this conference



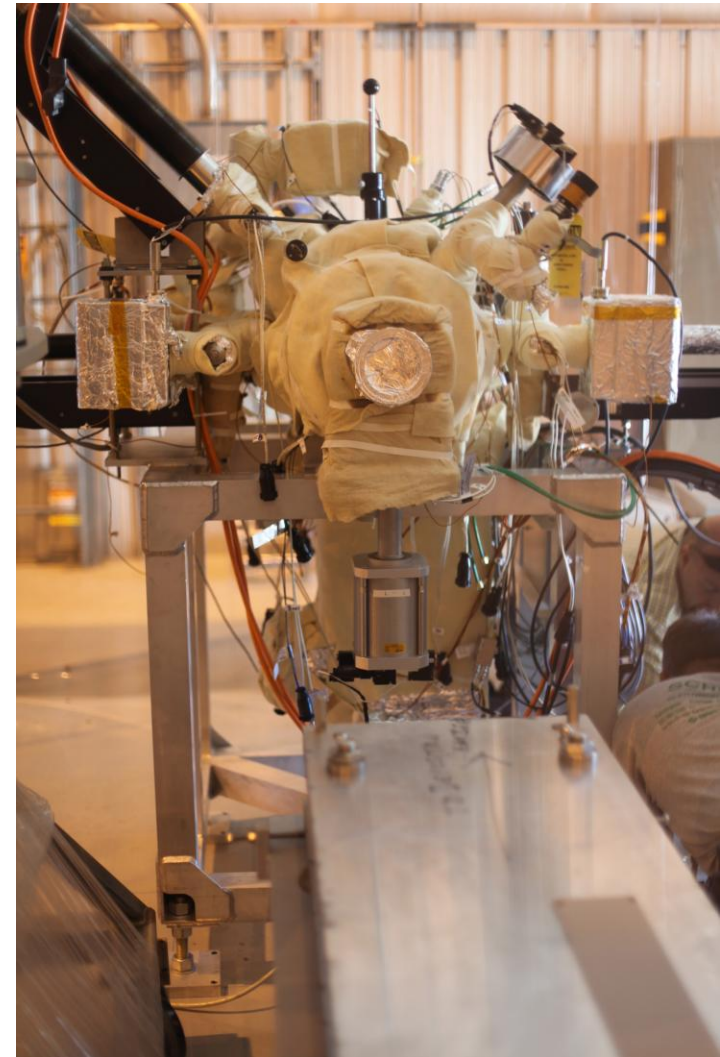
High QE Photocathode for RF gun

Deposition System

- 2 transport units to deliver cathodes
- Base pressure 1×10^{-10} Torr
- System designed to eliminate cross contamination of sources
- Provides for quicker source exchange
- Robust CsK₂Sb photocathode, high QE (8%) and low thermal emittance (0.37 microns / mm-rms) at a wavelength of 543 nm.

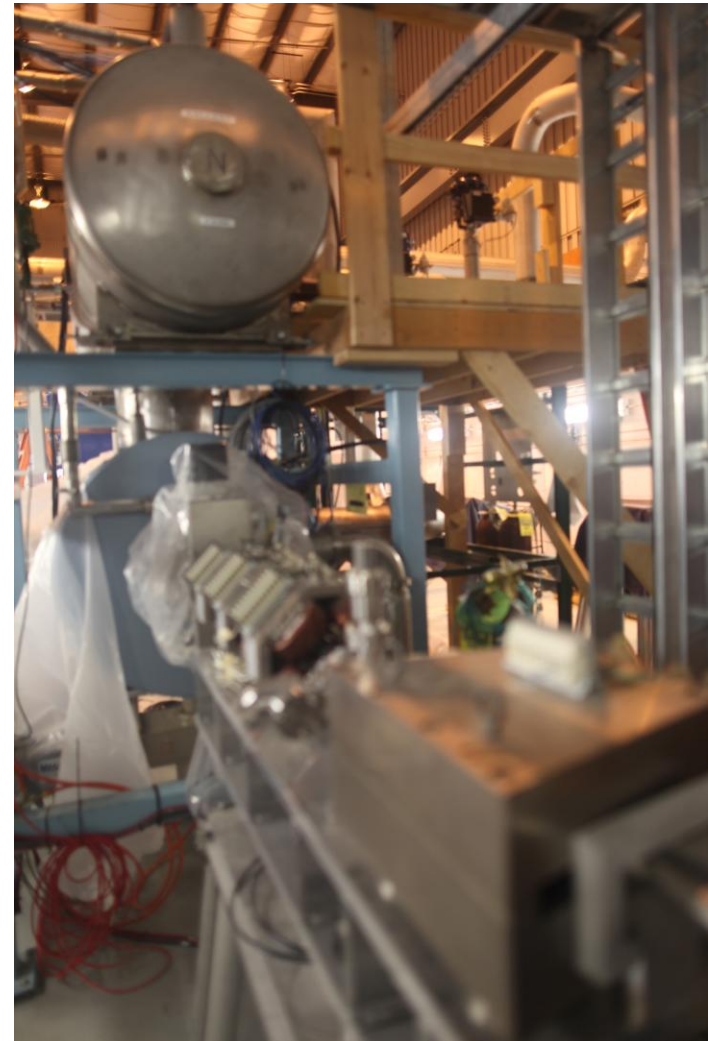
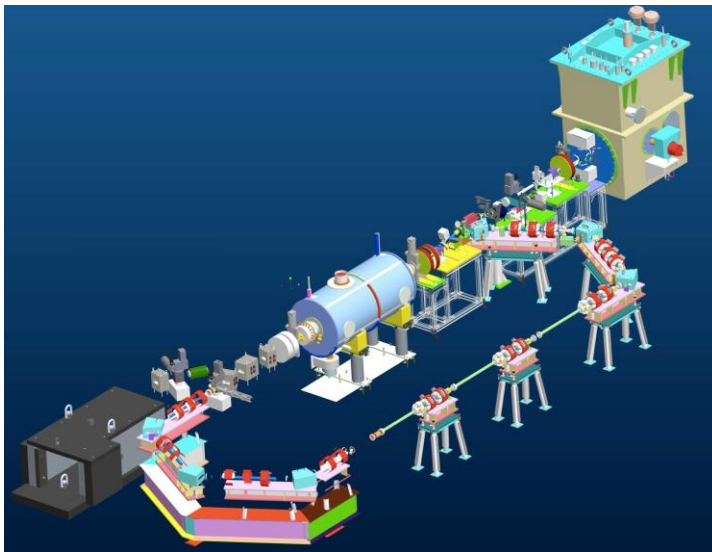
Transport unit

- 2 UHV systems with LN₂ cooling
- Precision mounting to gun and preparation chamber

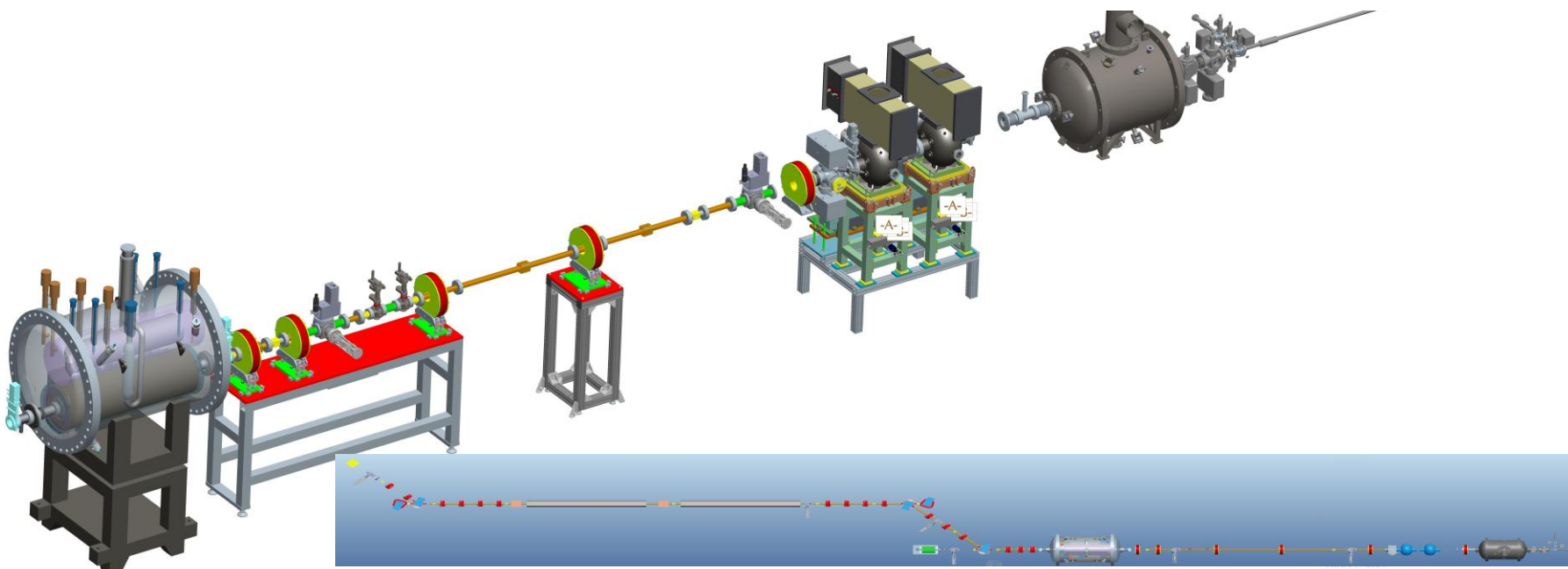
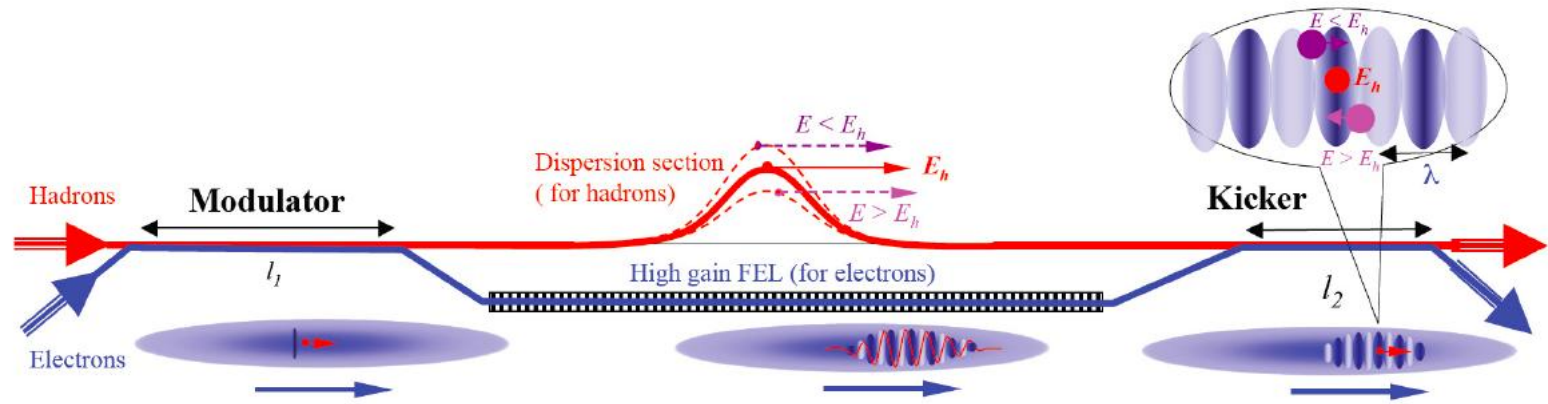


R&D ERL, target: 500 mA at 20 MeV

- Test the key components of the High Current SRF ERL
- Test the beam current stability criteria for CW beam currents
 - measure beam quality
 - measure halo
 - measure spurious radiations

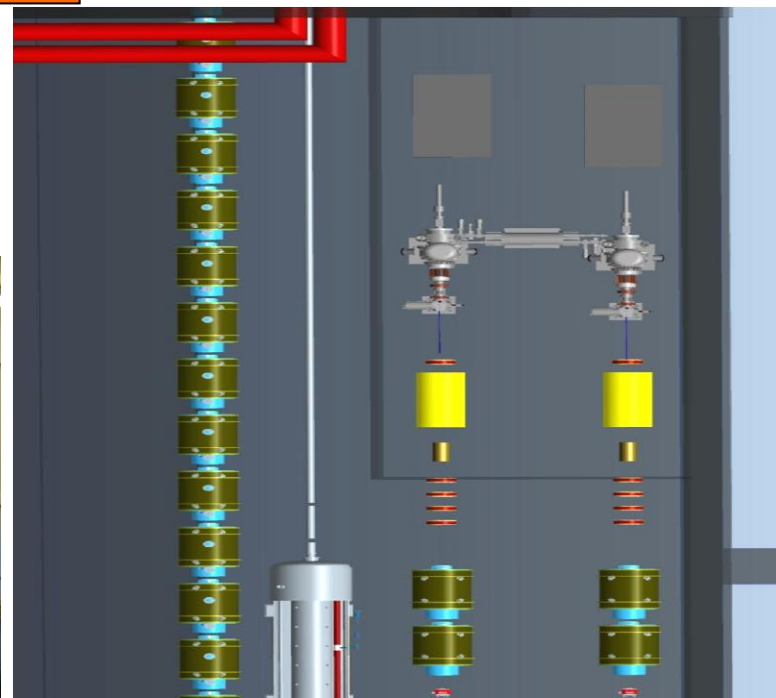
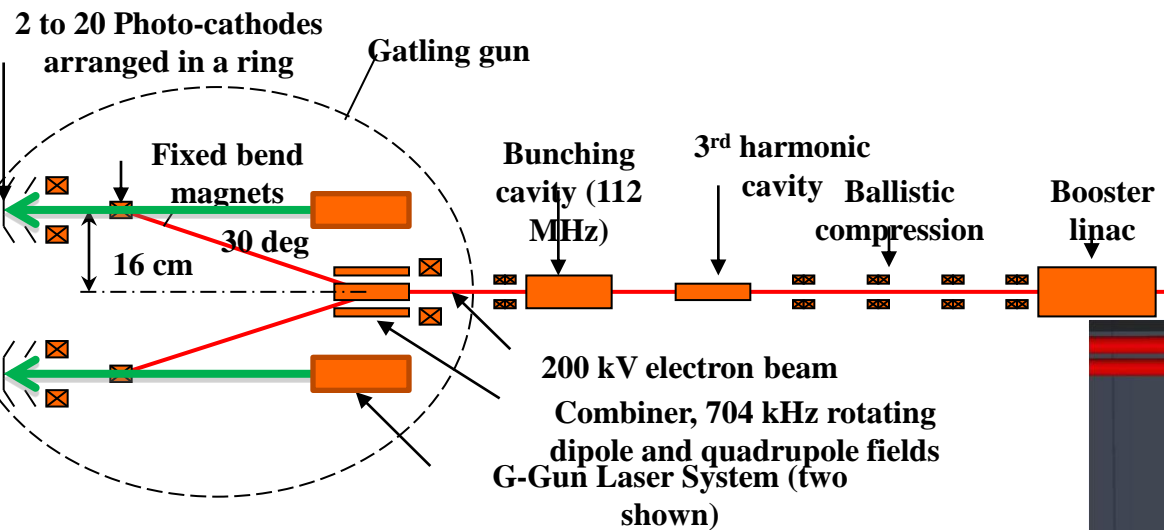


Coherent electron Cooling Proof-of-Principle experiment



X.XXX +0.001

20 cathode funneling polarized electron gun (“Gatling Gun”)



Summary

- ◆ RHIC is a highly successful ion and polarized electron collider.
- ◆ eRHIC is proposed as the addition of an electron ERL to collider (polarized) electrons with (polarized) RHIC beams.
- ◆ The eRHIC electron machine is a high-energy, high-current ERL.
- ◆ R&D is currently carried out on the eRHIC collider design, including various elements of the ERL, to reduce the risk and/or cost of the machine:
 - ◆ The 50 mA polarized electron gun
 - ◆ Coherent electron Cooling proof-of-principle experiment
 - ◆ A 300 mA 20 MeV R&D ERL
 - ◆ Highly-damped 704 MHz 5-cell ERL cavities